National Aeronautics and Space Administration

Cutting edge
Goddard's Emerging Technologies

All Aboard the 3D Train

Volume 10 | Issue 2 | Winter 2014

in this issue:

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SPECIAL REPORT

This issue of CuttingEdge examines NASA's pursuit of 3D manufacturing, an emerging manufacturing process involving CAD models and sophisticated printers that literally lay down successive layers of plastic, metal, or some other material to eventually create an object. One article addresses R&D efforts across NASA, while the second focuses exclusively on those at Goddard.

NASA Jumps Aboard the 3D-Manufacturing Train

Just three decades ago, it seemed the stuff of science fiction that someone might manufacture a human skull, an aircraft wing, or even a bionic ear using only a CAD model and a sophisticated 3D printer.

Today, 3D or additive manufacturing — the process of laying down successive layers of metal, plastic, or some other material to create an object — is a $2-billion-a-year industry that is projected to grow to $6 billion by 2017.

Useful Tool for Prototyping

Although some visionaries hype the technology as the next industrial revolution, others take a more prosaic view. They believe it will never completely replace traditional or subtractive manufacturing. It will remain — at least for the short term — an exceptionally useful tool for prototyping or building highly customized, low-production-run products needed by a range of users, including everyone from medical-device to aerospace manufacturers, these experts say.

Given NASA's unique needs for highly customized spacecraft and instrument components, the technology offers a compelling alternative to more traditional manufacturing approaches, said Ted Swanson, the assistant chief for technology for Goddard's Mechanical Systems Division and the center's point-of-contact for 3D manufacturing.

"We're not driving the additive manufacturing train, industry is," he said. "But NASA has the ability to get onboard to leverage it for our unique needs."

For the past several years, that's precisely what's been happening at Goddard and other NASA centers around the nation.

Led by NASA's Space Technology Mission Directorate (STMD), the Agency has launched a couple of formal programs to prototype new design concepts and tools for current and future missions. In addition to working with the U.S. Air Force, NASA has joined America Makes, formerly known as the National Additive Manufacturing Innovation Institute (NAMII), a public-private partnership created

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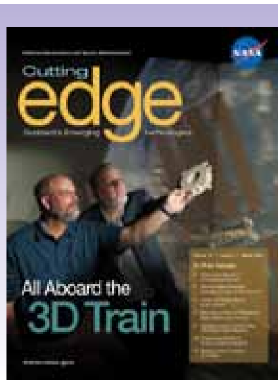

About the Cover

Goddard technologists Ted Swanson and Matthew Showalter hold a 3D-printed battery-mounting plate developed specifically for a sounding-rocket mission. The component is the first additive-manufactured device Goddard has flown in space.

Cover Photo Credit: Pat Izzo/NASA

Clarification

In the Fall 2013 issue of *CuttingEdge,* we published a story announcing technologist Tom Flatley's selection as the FY13 "IRAD Innovator of the Year." The article described the many attributes of the SpaceCube flight-processor technology and Flatley's role advancing the technology. We need to clarify that although SpaceCube is an especially powerful onboard-processing technology for science applications, it is not yet rated for safety-critical, mission-critical or man-rated operations.

Goddard's Storied Tradition Potentially Expanded Through 3D Manufacturing

For the past two years, Goddard's Internal Research and Development (IRAD) program has awarded research dollars to a handful of principal investigators who are investigating how they might benefit from additive manufacturing, an emerging technology where computer-operated devices literally print solid objects from powdered metals or some other material, layer by layer until they are complete.

"We're not looking to reinvent the wheel or pursue applications that industry already can do with 3D manufacturing," said Goddard Chief Technologist Peter Hughes. "We're interested in finding out how this technology can enhance our ability to create one-of-a-kind instruments and components geared exclusively to studying and operating in space; in other words, improve what we already do well."

Thermal Control

One area that could potentially benefit from 3D manufacturing is electronics, particularly the techniques that technologists use to remove heat from heat-sensitive computer chips. "There is room for optimism," said Principal Investigator Jeffrey Didion, who is involved in a comprehensive, multi-year effort to advance electrohydrodynamic (EHD)-based thermal control for removing heat from spacecraft electronics (*Goddard Tech Trends*, Winter 2011, Page 2).

Unlike traditional thermal-control technologies that rely on mechanical pumps and other moving parts, EHD uses electric fields to pump coolant through tiny ducts inside a thermal cold plate. From there, the waste heat is dumped onto a radiator and dispersed far from heat-sensitive circuitry that must operate within certain temperature ranges. The advantages are many. Without mechanical parts, the system is lighter and consumes less power and space.

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Photo Credit: BillHrybyk/NASA

Above: Principal Investigator Beth Paquette holds the Goddard-developed Housekeeping-System-on-a-Chip designed to monitor everything from voltages and currents to temperature levels. With this device, she defined the process for bonding the chip onto a printed wiring electronics board.

Below: A close-up of the housekeeping chip that was bonded onto an electronics board.

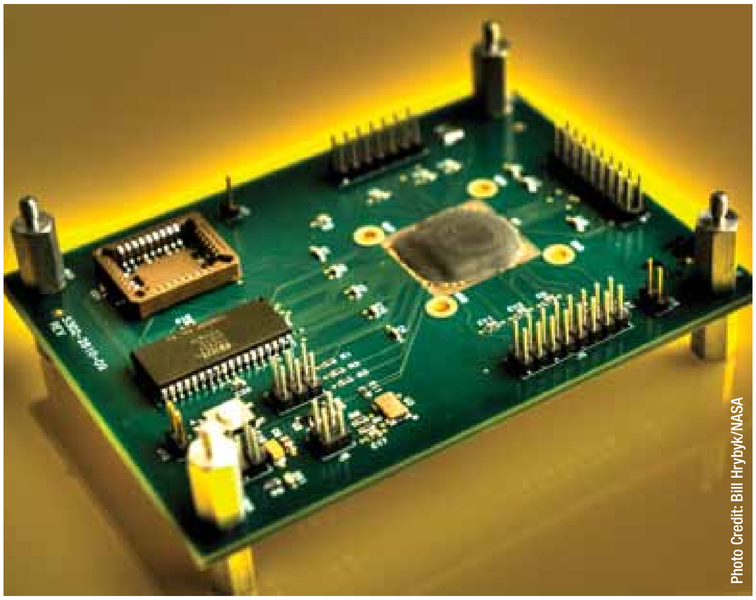

Photo Credit: Bill Hrybyk/NASA

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Inspired by an Umbrella

NASA Team Wins Funding to Develop Next-Generation Entry System

Photo Credit: NASA

In August 2013, an Ames-led team installed a cloth cover on an engineering prototype of the Adaptable, Deployable Entry and Placement Technology, also known as ADEPT, a mechanically deployable semi-rigid aeroshell entry system.

A 3,000-year-old technology originally conceived in ancient Egypt to protect nobility from sunlight has inspired a NASA team now developing a new technology that would shield a potential lander mission to Venus or another planet from the extreme heat of entering the planet's atmosphere.

Under the NASA-funded collaboration, the Ames Research Center in California's Silicon Valley is developing the carbon-fiber material and struts for the Adaptable, Deployable Entry and Placement Technology (ADEPT), while Goddard is responsible for developing the mechanism that connects the payload to the shield and overseeing the testing. The team's goal is to create and fully test within three years a six-meter prototype that could lay the foundation for ADEPT's use on a possible next-generation Venus lander.

"We were inspired by an umbrella," said Lori Glaze, a Goddard scientist who is collaborating with Ames to advance the ADEPT concept. "It's a very simple mechanical concept, an elegant solution."

Funded by NASA's Space Technology Mission Directorate's Game Changing Development Program, the ADEPT system would open much like an umbrella to allow an instrument-laden lander to safely enter a planet's atmosphere.

When a spacecraft is travelling through space, it reaches speeds of thousands of miles an hour. Upon entering the atmosphere, the spacecraft is moving so fast against the atmosphere that friction causes the chemical bonds of the air molecules to break, producing electrically charged plasma around the spacecraft. Entry systems are necessary to slow any spacecraft to a safe landing speed while protecting the payload from this extreme heat.

"The concept is game-changing in that it generates a large surface area, mechanically deployed, to create drag," said Paul Wercinski, the ADEPT project manager. "Once free of the Earth and on its way to Venus, the spacecraft carrying the ADEPT umbrella deploys fully and locks into position. The large deployed area creates a low-ballistic coefficient, which means the heating conditions and deceleration loads, also known as g-forces, are 10 times lower than a conventional entry system."

"This is the breakthrough!" Wercinski continued. "We're finding a way to deliver a 1,000-kg science payload to Venus and have it only see 30-g's peak deceleration rather than 300-g's with other entry systems."

A Soviet-era lander snapped this photo of the Venusian surface. A NASA team would like to land its own mission on this strange and forbidding planet.

A Step Beyond Aeroshell Technologies

Currently, NASA uses rigid, aeroshell-type technologies to protect landers and other spacecraft from the perils of entering the atmosphere of a planet, whether it's the Earth, Mars, or even Venus.

However, current technologies are not ideal for a future lander mission to Venus, particularly one mission concept endorsed by the Planetary Decadal Survey issued by the National Research Council. That mission, called the Venus Intrepid Tessera Lander (VITaL), would follow from where NASA's Magellan mission left off, but with a twist. While Magellan orbited the planet mapping 98 percent of the planet's volcano-pocketed surface during its four-year sojourn, VITaL would actually land on the surface.

Equipped with a large payload similar in size to the Curiosity rover now exploring Mars, VITaL would sample the Venusian atmosphere during its one-hour descent. After landing, preferably in the "highlands," it would then spend another two hours snapping photos and taking chemical and mineral measurements before the planet's forbidding environment destroyed it.

Although the former Soviet Union successfully landed seven probes on Venus in the 1970s and 1980s, neither NASA nor any other space-faring nation has attempted to do so.

"What's stopping us with VITaL is cost," said Glaze, a volcanologist intrigued by Venus, which, when compared with Earth, rotates very slowly and backwards.

The big driver, she said, is the trip through the atmosphere. Traditional entry designs aren't feasible because the size of the drag surface would create high-deceleration forces on the vehicle and the payload. As a result, scientists would have to take additional measures to protect their instruments, making qualification more time-consuming and costly. But by enlarging the heat shield, while reducing its weight, mission planners could lessen the deceleration force and risk to the instruments.

ADEPT does just that.

The umbrella-like device would be equipped with a lightweight 3D carbon-fiber canopy, ribs and struts, offering a larger surface area that weighs significantly less than more traditional techniques. Even better, it would easily fit inside a typical four-meter rocket fairing when fully stowed.

Applicable to Other Planetary Missions

"This is a radical design," Glaze said. "And it can be used for other missions. It would work equally as well on Mars."

Should the team succeed, she said NASA would be in a good position technologically to return to Venus. A possible payload suite could include the same instruments now operating on Curiosity. "We know they work. They're ready to go," Glaze said.

"It's time for NASA to go to Venus," she said. "There are tons of questions that we haven't answered." ❖

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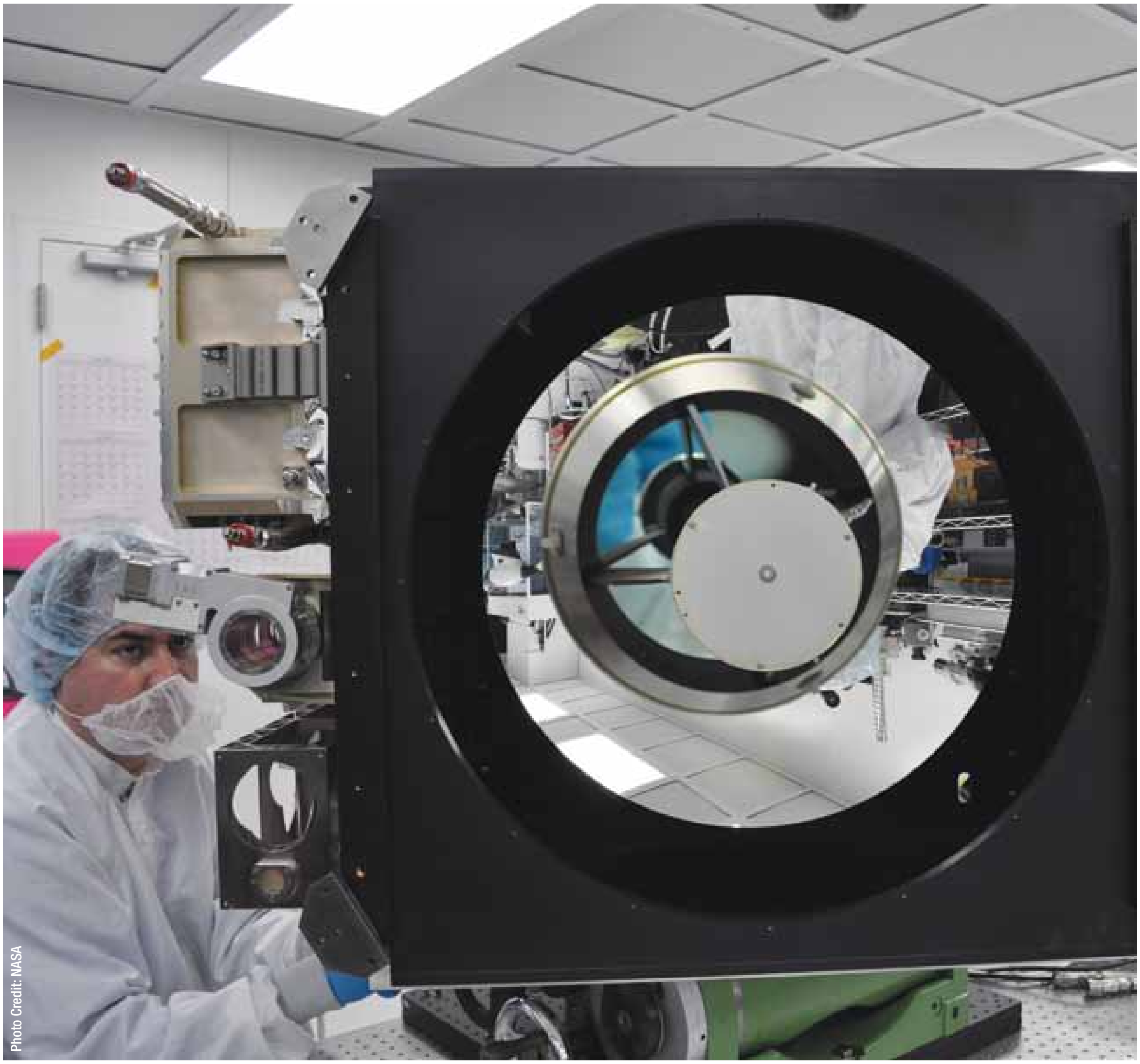
CATS in Space

New Measurement Capability to Fly on the International Space Station



Stan Scott, CATS instrument manager and optical lead, is shown here assembling the CATS transceiver (laser transmit/telescope receive) unit.

Four years ago, Iceland's Eyjafjallajökull volcano erupted, ejecting a massive plume containing tiny particles that posed a threat to aircraft engines. European air traffic-control officers canceled commercial flights and NASA grounded its own research aircraft due to potential risks to passengers and crew.

If such an event were to happen again, however, officials could be armed with more of the data they need to understand the safety conditions.

A new instrument called the Cloud-Aerosol Transport System (CATS), advanced through NASA and Goddard R&D funding, is scheduled to launch to the International Space Station (ISS) later this year as a technology-demonstration project.

It will demonstrate for the first time three-wavelength laser technology for measuring volcanic particles and other aerosols from space. Developed by Goddard scientist Matt McGill and his team, CATS will determine the character and worldwide distribution of aerosols — tiny particles that make up haze, dust, air pollutants, and smoke — as it passes over them. When it begins operations from its docking port on the Japanese Experiment Module-Exposed Facility, the refrigerator-size CATS will continue measuring atmospheric aerosols using the same two-laser wavelengths as NASA's CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) mission — the 1064 and 532 nanometer wavelengths.

Third Wavelength Added

What makes CATS stand out, however, is that it will incorporate a third laser wavelength — 355 nanometers. This will deliver more detailed information revealing whether the particles scientists see in the atmosphere are dust, smoke, or the product of a volcano. CATS also is equipped with extremely sensitive detectors that can count individual photons, delivering better resolution and finer-scale details, McGill said.

"You get better data quality because you make fewer assumptions, and you get, presumably, a more accurate determination of what kind of particles you're seeing in the atmosphere," McGill said.

While CALIPSO can deliver 20 pulses of laser light per second, using, as McGill described it, a whopping 110 milliJoules of energy in each of those pulses, CATS will fire 5,000 laser pulses per second, with only about one milliJoule for each pulse. CATS's power and thermal requirements are greatly minimized — a huge plus for space-borne applications.

Science from the Space Station for Earth Purposes

Knowing where aerosols are occurring in the atmosphere — such as smoke from forest fires, dust blowing off vast deserts, and plumes from erupting volcanoes — is often critically important. These particles can affect weather, the safety of airplane transportation, and human health.

The space station is the perfect berth for gathering these measurements, McGill said. The station travels in a precessing orbit — it shifts around and around, traveling from 51 degrees North latitude to 51 degrees South latitude. As a result, CATS will provide good coverage of what's happening over primary population centers.

In addition, the station passes over and along many of the primary aerosol-transfer paths within Earth's atmosphere, McGill added. One of Earth's primary transport routes for airborne pollutants is from Southeast Asia. Circulation cells in Earth's atmosphere transport particles over Japan, northward south of Alaska, and then south toward the West Coast of the United States, making a big, inverted "U" shape. Another atmospheric circulation cell moves aerosols from western Canada eastward and then southward, over the Great Lakes and the East Coast.

Because smoke-darkened skies over cities and communities can pose health risks to populations, especially to the medically vulnerable, the ability to track those aerosols and deliver warnings is critical, McGill said. Long-term data also can reveal the shifts that are occurring in global climate — whether changes are occurring in cloud cover or whether the level of pollutants is increasing or decreasing — over geographic distances and time.

Lessons for the Future

The demonstration flight using the space station as a testbed also is technologically important. The third laser wavelength is in the ultraviolet, just outside the visible range. Though it adds an advanced capability, particularly when coupled with the new detectors, scientists believe it is susceptible to contamination, McGill said. "If you get contamination on any of your outgoing optics, they can self-destruct, and then your system's dead. You end up with very limited lifetime."

"So the way to combat that is do a quick-and-dirty demo from space, and show that it can last for months. ISS is a good, relatively low-cost, quick way to do that. In our current budget-constrained environment, we need to use what we already have, such as the ISS, to do more with less," McGill said, adding that if the instrument works, it can be scaled up to be a free-flier mission.

"One of the most exciting things for me has been the opportunity to develop a small, low-cost, quick-turnaround payload for the ISS, a pathfinder project representing what's possible for future technology investigations," he added. "We did this using a small team, a streamlined process, and a build-to-cost mentality — and we proved it can be done." ❖

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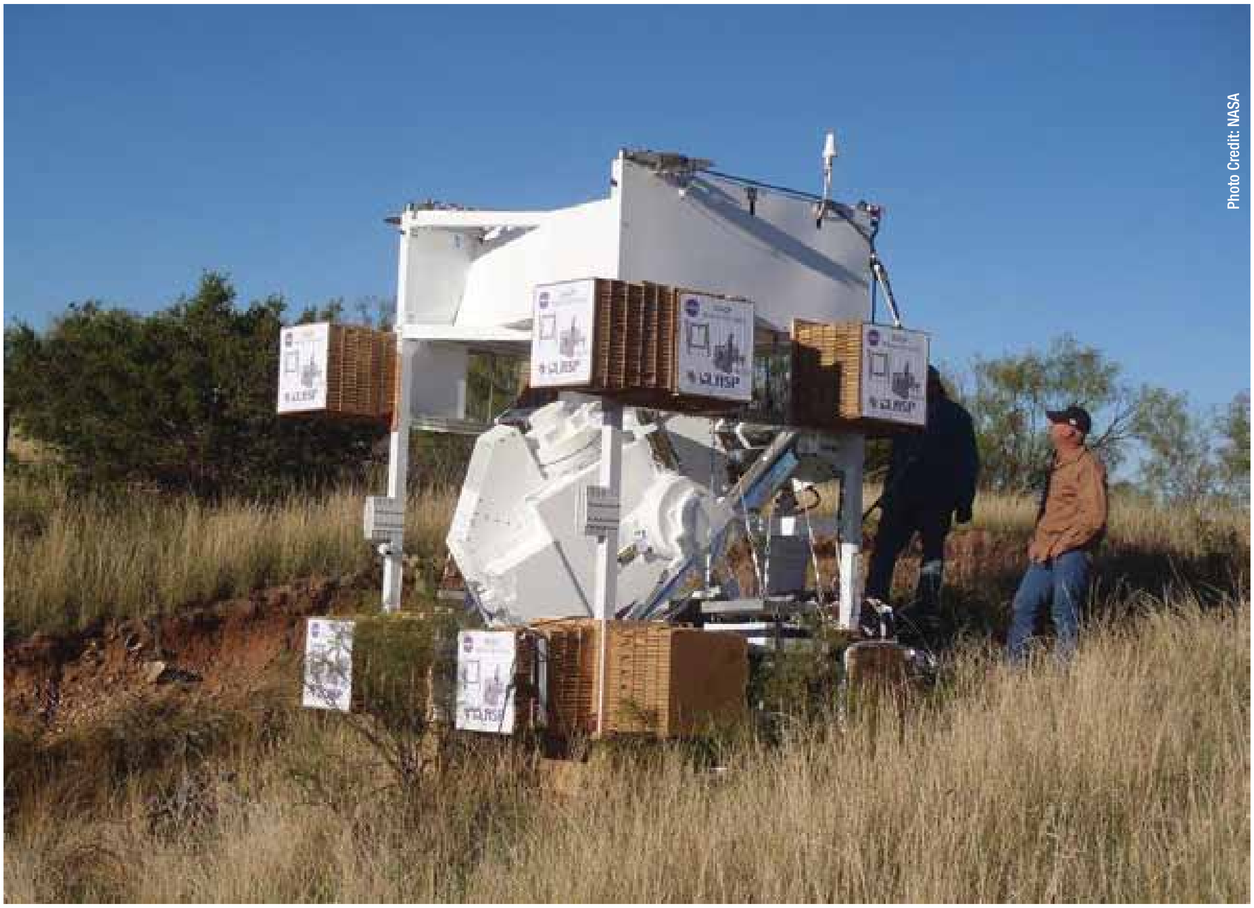
At Long Last…Planetary Scientists Have a Tool that Enables Balloon-Borne Investigations



Scientists used the Wallops Arc Second Pointer to precisely point the HyperSpectral Imager for Climate Science during a balloon mission in September. Shown here after it landed, the imager collected radiance data for nearly half of its eight-and-a-half hour flight.

Scientists who study the Earth, sun, and stars have long used high-altitude scientific balloons to carry their telescopes far into the stratosphere for a better view of their targets. Not so much for planetary scientists. That's because they needed a highly stable, off-the-shelf-type system that could accurately point their instruments and then track planetary targets as they moved in the solar system.

That device now exists.

The Wallops Flight Facility has designed a new pointing system — the Wallops Arc Second Pointer (WASP) — that can point balloon-borne scientific instruments at targets with sub arc-second accuracy and stability. A planetary scientist — interested in finding less-expensive platforms for observing Jupiter and other extraterrestrial bodies — now plans to test drive the device later this year.

"Arc-second pointing is unbelievably precise," said Dave Stuchlik, the WASP project manager. "Some compare it to the ability to find and track an object that is the diameter of a dime from two miles away."

WASP is designed to be a highly flexible, standardized system capable of supporting many science payloads, Stuchlik added. Its development frees scientists, who in the past had to develop their own pointing systems, to instead focus on instrument development. Given the technology's potential, the WASP team has received NASA Science Mission Directorate funding to further enhance the new capability as a standard support system.

Flight Proven

First tested in 2011 and then again in 2012, the most recent test flight occurred from Fort Sumner, N.M., in September. During that flight, a 60-story balloon lifted an engineering test unit of the HyperSpectral Imager for Climate Science (HySICS) to an altitude of nearly 122,000 feet, far above the majority of Earth's atmosphere. From this vantage point, WASP precisely pointed HySICS so that it could measure the Earth, the sun, and the moon.

Developed by Greg Kopp of the University of Colorado's Laboratory for Atmospheric and Space Physics, the imager collected radiance data for nearly half of its eight-and-a-half hour flight, demonstrating improved techniques for future space-based radiance tests. Kopp now is preparing his imager for another balloon flight this September.

OPIS Inaugural Flight

Also planned for September is the inaugural flight of the Observatory for Planetary Investigations from the Stratosphere (OPIS) — a notable event because so few planetary scientists have in the past employed less-expensive balloon craft to fly their instruments.

"Planetary scientists really haven't been involved in balloon payloads," said OPIS Principal Investigator Terry Hurford. "Planetary targets move with respect to the stars in the background. And because you need to track them to gather measurements, you need a system that can accurately point and then follow a target. These challenges are why planetary scientists haven't gotten into the balloon game."

For other scientific disciplines, the tolerances aren't as tight, he added. The targets are either large, like the sun, or plentiful, like the stars, thereby making it much easier to target an object and then maintain a lock onto that object, Hurford said.

Now that Stuchlik and his team have proven WASP's effectiveness, Hurford wants to show that the system is equally as effective for planetary science when he flies his balloon-borne OPIS high above Earth's surface to study Jupiter and planets beyond the solar system.

He is using Goddard Internal Research and Development program funding to repurpose a telescope mirror originally built to calibrate the Goddard-developed Composite Infrared Spectrometer now flying on NASA's Cassini mission. He also is using the support to help upgrade WASP's existing avionics system to assure planetary tracking and expand its ability to follow targets above 25 degrees of elevation.

Like HySICS, OPIS will launch from Ft. Sumner.

Principal Investigator Terry Hurford poses with a 21-inch-diameter mirror originally built for a telescope that helped calibrate an engineering model of the Cassini Composite Infrared Spectrometer (CIRS). A CIRS team member found the mirror and Hurford is now repurposing it for his OPIS project.

Provided stratospheric winds cooperate, the mission is expected to last up to 24 hours during which Hurford plans to gather time measurements of Jupiter's atmospheric structure. His other objectives during his 24-hour flight are to observe a transit of an extrasolar planet and the rotation of an asteroid.

"Time for planetary observations on ground-based observatories is difficult to obtain," Hurford said. "Moreover, high-altitude balloons above 95 percent of the Earth's atmosphere allow for observations in the ultraviolet- and infrared-wavelength bands, which aren't possible with ground-based telescopes. And given NASA's constrained budget and high cost of missions to the outer solar system, high-altitude balloons offer us a unique, low-cost platform to carry out our planetary observations. This effort provides us with a unique opportunity to build a capability that we can leverage for future opportunities. WASP gives us a new platform." ❖

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A Spectacular Mission of Firsts for Bustling Spaceport

Photo Credit: Ed Campion/NASA

The Minotaur rocket carrying 29 small satellites, including the Goddard-developed Firefly, is seen over the Annapolis, Md., skyline.

A spectacular launch from Virginia's eastern shore in mid-November resulted in the successful deployment of a record-breaking 29 small satellites into orbit, but that wasn't the only first for the mission or the bustling spaceport at the Wallops Flight Facility.

Range-safety officers also used the ORS-3 mission, run by the U.S. military's Operationally Responsive Space Office (ORS), to carry out the first of three planned certification tests of a new technology that promises to eventually eliminate the need for expensive down-range tracking and command infrastructure to manually abort rockets if they veer off course.

According to Barton Bull, the chief engineer of the Wallops Research Range, the Minotaur 1 four-stage rocket carrying the Air Force's Space Test Program Satellite-3 (STPSat-3) and 28 other so-called CubeSats also carried a compact Autonomous Flight Safety System (AFSS) unit that integrated GPS, an inertial measurement unit, and Wallops-developed algorithms to track the rocket's path as it lifted off the gantry and streaked across the horizon.

Developed by ATK, a supplier of aerospace and defense products from its location in Plymouth, Minn., the shoe box-size unit worked in shadow mode during its first certification test. As part of that test, range officers programmed the unit to respond to a simulated signal indicating that the rocket had gone off course and to send a self-destruct or detonate command at the appropriate time.

Initial Data 'Positive'

"We're still looking at the data, but initial indications are pretty positive," said Bull, whose organization created the unit's software. "Preliminary data indicate that the unit sent the simulated termination command at the right time."

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Traditionally, range-safety officials use radar from ground stations operating in the Outer Banks of North Carolina, Bermuda, and Antigua to track flight vehicles and a ground-based command system to abort rockets that deviate from their flight plans. Due to increasing costs to maintain and staff these systems, NASA and the military launched a program several years ago to develop an autonomous system that would migrate flight-safety functions onto the rocket itself.

"All these systems need to be tied together and that costs money and time," Bull said. "Our objective is to save money and allow faster decision-making."

Initial testing of AFSS began more than three years ago (*Goddard Tech Trends,* Fall 2010, Page 5). However, in those flight demonstrations the team used a system cobbled together with commercial-off-the-shelf components married to the Wallops-developed software. The certification test during ORS-3, however, employed the actual unit that ATK built under contract.

As a result of the unit's successful certification, the AFSS team plans to execute another test during a rocket launch from Barking Sands, Hawaii, in the coming months. Once the team finishes the certification, it believes AFSS will become fully operational in a couple years.

New Mission Graphics System Debuts

In addition to carrying out the first AFSS certification test, the mission debuted and tested a new, user-friendly mission-graphics system that updates radar and other data on a computer screen, Bull said. "It takes an enormous amount of time to set up these systems" and make sure all the data, which typically arrive in different formats, are easily displayed, he added. The new system is more configurable and faster to set up.

"This was a mission of firsts on many different levels," Bull said. The team deployed a record-breaking 29 CubeSats, including, among others, the Goddard-developed Firefly, which is studying lightening and more particularly its possible connection to incredibly powerful bursts called terrestrial gamma-ray flashes, or TGFs, just miles off the ground. Also onboard were NASA's so-called "PhoneSat," which is testing a smartphone's capability as a communication technology for nanosatellites, and 11 student-developed research satellites. A student team from a high school in Alexandria, Va., provided one of the 11, also a first. "I think we were all pleased with the results," Bull said. ❖

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Mapping Earth's Cropland from Space

It takes a lot of land to grow food for the world's seven billion people. About a third of Earth's terrestrial surface is used for agriculture. And about a third of that, in turn, is used to grow crops. Now, a new NASA-funded effort aims to map crop fields worldwide, identify what's growing where, and determine whether it's irrigated or fed by rain.

But making those maps will take more than satellite data. It will require special software, and that's where Goddard computer engineer James Tilton can help.

Tilton will apply and build on a software program he developed for another NASA project to help NASA's MEASURES program, which stands for Making Earth System Data Records for Use in Research Environments, map 3.7-billion acres of cropland worldwide.

"The idea of this project is to have an accurate cropland data set," said Prasad Thenkabail, the principal investigator of the MEASURES project and a research geographer with the U.S. Geological Survey in Flagstaff, Ariz. "Ultimately, it will help provide a better accounting of water use, cropland productivity, and water productivity — all critical information for studying global food security."

The first step in this five-year project is locating and mapping the fields. However, that can be a challenge in countries that have little, if any, data on what farmers grow, or in countries that refuse to provide accurate information on what is growing where. "The satellite platforms offer an opportunity to look at the entire world in a unique way," Thenkabail said. "It has no bias."

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3D Manufacturing, *continued from page 2*

to transition the technology into the mainstream U.S. manufacturing sector.

As a result of these efforts and others sponsored by the individual centers, teams of engineers and scientists are investigating how their instruments and missions might benefit from an industry that actually began more than two decades ago, with the introduction of the world's first 3D system.

"This effort really goes beyond one center," said Matt Showalter, who is overseeing Goddard's disparate 3D-manufacturing efforts, believing Goddard technologists and scientists will benefit most from collaborations with others also investigating the technology's benefits. "It's in the national interest to collaborate with other institutions. This is a powerful tool and we need to look at how we can implement it. For us, it's a team effort."

Diverse Applications

Currently, at least six NASA centers, including Goddard, have begun applying the technology to a number of applications pertinent to their areas of expertise.

Goddard, for example, is devoting R&D resources to evaluate its usefulness for a variety of instrument-development efforts (see related story, page 3). The Langley Research Center, meanwhile, has developed a green-manufacturing process, called the Electron Beam Freeform, or EBF3. It uses an electron-beam gun, a dual-wire feed, and computer controls to remotely manufacture metallic structures for building parts or tools in hours, rather than days or weeks.

The Kennedy Space Center is currently investigating the use of in-situ regolith or soil on extraterrestrial bodies as feedstock for building 3D habitats and other structures. The Ames Research Center, meanwhile, is exploring the manufacturing of biological materials — everything from construction materials to foodstuffs — from small stocks of cells. The Glenn Research Center collaborated with Aerojet Rocketdyne of West Palm Beach, Fla., to fabricate and successfully test an engine ejector for the RL-10 rocket.

And the Marshall Space Flight Center, which has used 3D manufacturing to create components for the J-2X and RS-25 rocket engines, now is working with Made In Space, a Silicon Valley start-up, to develop a 3D printer that astronauts could use on the International Space Station or other locations within the solar system. The idea is that astronauts could create tools and replacement parts they would need to operate in space, eliminating the need to transport these items there. The team plans to fly the device on the International Space Station in September 2014.

"NASA's work with additive manufacturing should enable us to be smart buyers and help us save time, expense, and mass," said LaNetra Tate, the advanced-manufacturing principal investigator for STMD's Game Changing Development Program.

"With additive manufacturing, we have an opportunity to push the envelope on how this technology might be used in zero gravity — how we might ultimately manufacture in space," she said. ❖

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This battery case, created with a material called Polyetherketoneketone (PKK), is the first 3D-printed component Goddard has flown. Developed under a university-industry partnership, the part was demonstrated during a sounding-rocket mission testing a thermal-control device developed in part with Goddard R&D funding.

Storied Tradition, *continued from page 3*

But perhaps more significant, the system can be scaled to different sizes because mechanical hardware no longer drives the size or placement of the system within an electronics box.

A version of Didion's thermal-control device now is being demonstrated on the International Space Station. In addition, Didion carried out two validation experiments last year, one under variable gravity and the other during a sounding-rocket mission where he also demonstrated the usefulness of a battery case made of Polyetherketoneketone (pictured on page 12) — the first 3D-printed part Goddard has flown. With this year's IRAD and Center Innovation Fund support, Didion is investigating how he might use additive manufacturing to integrate EHD into the electronics board itself.

"What we'd like to do is look at integrating thermal management into a functioning electronics board," Didion said. "In theory, we could do a better job of packaging devices and reducing mass, power consumption, and volume" — a notable endeavor given NASA's push to reduce instrument size and fly a greater number of less-expensive CubeSats and other smaller spacecraft.

Electronics Packaging

To that end, he has joined forces with Principal Investigator Beth Paquette, who received IRAD funding this year to advance a common customizable instrument electronics package called MinE Pack. The device would combine different functions inherent in all instruments — housekeeping, data processing, power, digitization, control and data handling, and amplification — all onto a single three-dimensional chip or stack of chips.

"Our goal is to have all functions packaged into a component that could be plugged into a board or instrument," Paquette said. "To help us get there, we plan to use additive manufacturing that could print conductors from chip to substrate."

Last year, she focused on advancing MinE Pack's possible "housekeeping" function using the Goddard-developed "Housekeeping-System-on-a-Chip (HKSOC)," a structured, radiation-hardened application-specific integrated circuit designed to

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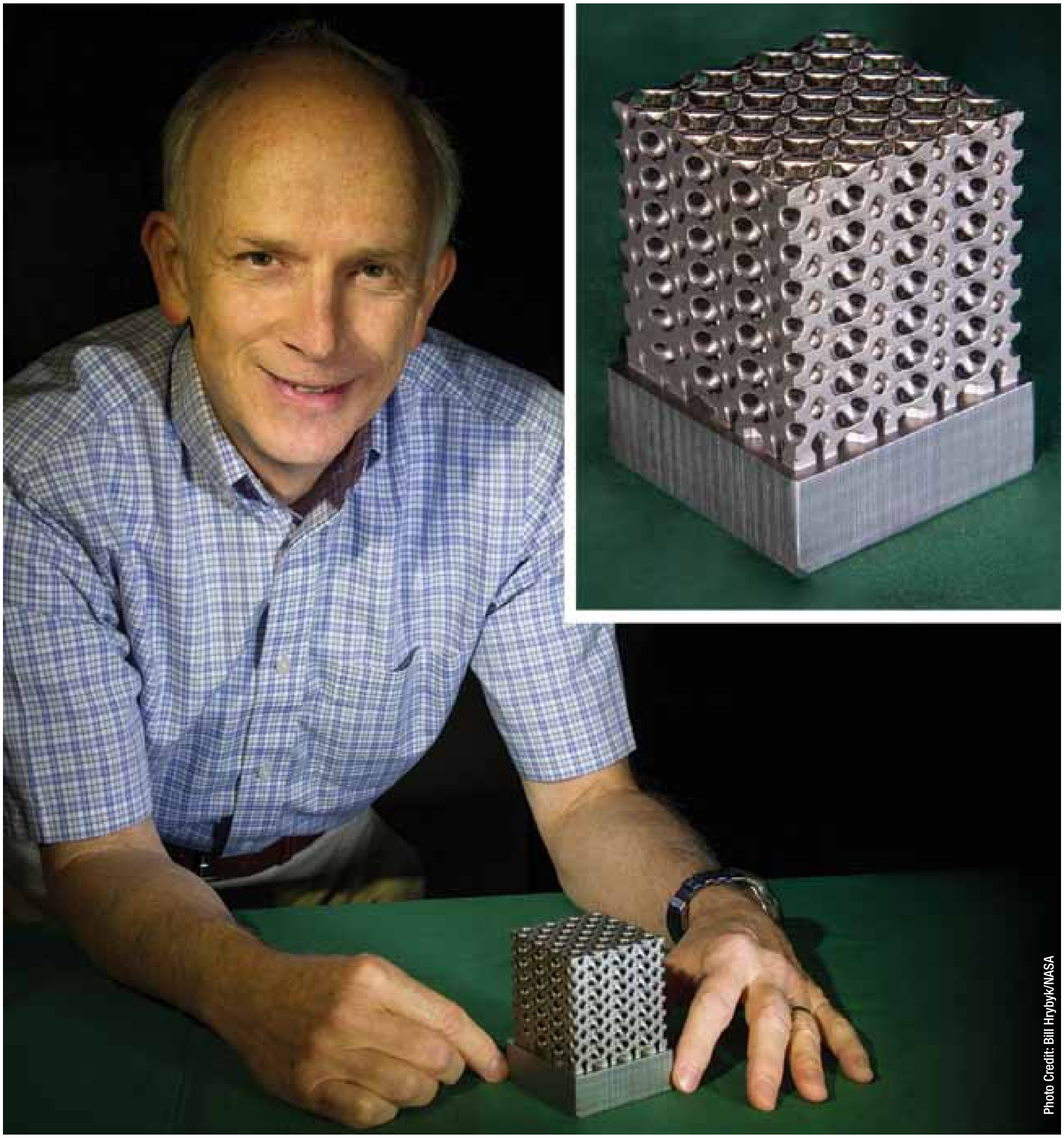
Photo Credit: Bill Hrybyk/NASA

Jean-Marie Lauenstein is investigating the use of 3D manufacturing to solve another electronics challenge — protecting sensitive circuitry from damage caused by exposure to space radiation. She is holding a printed Inconel-625 spot shield she created for an electronic component.



Tim Stephenson worked with EOS of America, Inc., to develop the first 3D-manufactured object made with Invar (inset) – a material especially useful for optical benches due to the material's immunity from shrinkage and expansion due to changes in temperature.

monitor everything from voltages and currents to temperature levels, all while consuming less than half a watt of power (*CuttingEdge,* Summer 2013, Page 12). Working with HKSOC's creator, George Suarez, she defined the process for bonding the housekeeping chip onto a printed wiring electronics board.

"The future is looking to additive manufacturing techniques in electronics packaging. This opens up a lot of opportunities for miniaturized packaging, while decreasing the costs of spacecraft electronics," she said.

Electronics Shielding

Principal Investigator Jean-Marie Lauenstein also is investigating the use of 3D manufacturing to solve another electronics challenge — protecting sensitive circuitry from damage caused by exposure to space radiation.

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"Dose from radiation can degrade performance to the point where the electronics no longer work," she explained. To protect them, instrument developers currently house sensitive components inside an electronics box made of metal. The thickness of that box depends in part on how much radiation the components are expected to encounter. Although the technique is effective, it "adds a tremendous amount of mass," she said. Engineers also use "spot shielding," which usually involves placing a slab of metal over the part.

However, she believes 3D manufacturing offers an intriguing alternative because the protective metal could be printed selectively to enclose the part, minimizing volume and maximizing protection. With her IRAD, Lauenstein used a computer code called NOVICE that not only calculated how much shielding a component required on a given side, but also created a CAD drawing that a 3D printer then used to build the shielding. "We print shields tailored for specific package types for a hand-and-glove fit to minimize mass and area," she said.

This year, her team plans to continue tests to make sure the printed shields can withstand the harsh environmental conditions encountered during launch and in space.

So far, Lauenstein is optimistic, believing 3D printing — and more precisely, a technique called direct metal laser sintering (DMLS) — could allow instrument developers in the future to use more state-of-the-art, non-radiation-hardened circuits and rely less on mass-intensive, box-level shielding. "We hope this will become one more tool in the toolbox for mitigating radiation-dose effects," she said.

Optical Benches and Telescopes

DMLS also could benefit instrument structures, said Goddard technologist Tim Stephenson. Working with the Michigan-based EOS of North America, Inc., he developed the world's first Invar structure produced by this technique, which literally prints objects from powdered metals.

Invar is weak and bends easily. However, it is stable and nearly immune to shrinkage or expansion due to extreme changes in temperature. As a result, it is ideal for optical benches and other instrument structures that demand stability. In fact, nearly a half-ton of the material was used to build the James Webb Space Telescope's Integrated Science Instrument Module, upon which the observatory's instruments hang. "Our goal is to see if we can lightweight these kinds of spacecraft structures through DMLS," Stephenson said.

He's upping the ante this year.

Under his IRAD award, Stephenson is working with Goddard astrophysicists to produce engineering prototypes satisfying the stability requirements for a coronagraph capable of detecting planets beyond the solar system. He also is fabricating a prototype cavity for the proposed Laser Interferometer Space Antenna, a concept to detect gravitational waves by monitoring the distance between three spacecraft.

> ***"This technology is developing so fast, it's hard even for us to stay on top of it."***
>
> *— Ted Swanson, an assistant chief for technology*

"The versatility inherent in additive manufacturing greatly expands an engineer's pallet," Stephenson added. "Fabrication of a complete CubeSat/MicroSat bus in a single step is now possible."

And another Goddard technologist, Jason Budinoff, has teamed with Stephenson to use DMLS to fabricate proof-of-concept, fully integrated 3D-manufactured telescopes. The goal is to not only decrease the costs and time needed to fabricate and align instrument assemblies, save mass, and increase dimensional stability, but also to drastically slash part counts and interfaces — a challenge that DMLS could meet, Budinoff said. Ultimately, he wants to gain experience with the technology and familiarize more engineers with the unique design considerations that 3D manufacturing requires.

His ambitions mirror those of Ted Swanson, assistant chief for technology for Goddard's Mechanical Systems Division. "My mission is to get the word out about this technology. We're only limited by our imaginations as to how we can use this technology to make our instruments and components smaller, cheaper, and better. This is just the start. This technology is developing so fast, it's hard even for us to stay on top of it." ❖

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Mapping Crops, *continued from page 11*

Goddard computer engineer James Tilton will apply a software program he developed to help NASA map 3.7-billion acres of cropland worldwide.

However, satellite data are made up of ones and zeros, and will have to be sorted to ultimately create the cropland maps. Tilton believes his software program, which identifies urban areas in Landsat's 30-meter, lower-resolution remote-sensing imagery, will help zero in on cropland, as well.

With satellite images at higher resolution, he has developed a program that identifies homogenous regions — areas like lakes, a block of buildings, or a field. "The software itself doesn't have any idea what it is," Tilton said. "It's just something that's similar in the spectrum."

This initial step identifies the ground-cover types of interest, using the high-resolution images from representative areas across the globe. Researchers use this to train a computer program, applying it to medium-resolution satellite images that cover a larger swath of ground — such as the 30-meter Landsat images. At that resolution, the program will scan the globe, looking for specific wavelengths indicating cities, cropland, or other features.

"I anticipate that a lot of what's developed for urban areas will be applicable, maybe with some minor modifications, to the new global cropland project," Tilton said.

One cropland-identification tool he's working on searches for edges or boundaries between different land-use areas that reflect different wavelength patterns. These could indicate agricultural field boundaries. In this program, the software would ignore gradual, subtle changes in neighboring pixels to look for more dramatic changes, resulting in a jigsaw-puzzle-like map of a region.

"If farmers have distinct fields, this should really help," Tilton said. But because agricultural practices differ around the globe, he knows challenges will arise. "For different areas, we'll change what we're doing….That'll be the experimental part."

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Cutting edge Goddard's Emerging Technologies

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